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Sertifikaat

REPUBLIEK VAN SUID AFRIKA

PATENT KANTOOR
DEPARTEMENT VAN HANDEL
EN NYWERHEID

Certificate

REPUBLIC OF SOUTH AFRICA

PATENT OFFICE
DEPARTMENT OF TRADE AND
INDUSTRY

Hiermee word gesertifiseer dat
This is to certify that

1) South African Provisional Patent Application No. **2003/4813** accompanied by a Provisional Specification was originally filed at the South African Patent Office on **20 June 2003,** in the name of **RAND AFRIKAANS UNIVERSITY** in respect of an invention entitled: **"Tunable Spectral Equalisation Filter for Amplified Spontaneous Emission Sources ".**

2) The photocopy attached hereto is a true copy of the provisional specification and drawings filed with South African Patent Application No. **2003/4813.**

Geteken te **PRETORIA** in die Republiek van Suid-Afrika, hierdie **26th** dag van **July 2004**
Signed at **PRETORIA** in the Republic of South Africa, this **26th** day of **July 2004**

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REPUBLIC OF SOUTH AFRICA	REGISTER OF PATENTS	PATENTS ACT, 1978

OFFICIAL APPLICATION NO.	LODGING DATE : PROVISIONAL	ACCEPTANCE DATE
21 2003/4813	22 20 June 2003	43
INTERNATIONAL CLASSIFICATION	LODGING DATE : COMPLETE	GRANTED DATE
51	23	

FULL NAME(S) OF APPLICANT(S) / PATENTEE(S)

71 RAND AFRIKAANS UNIVERSITY

APPLICANTS SUBSTITUTED :	DATE REGISTERED
71	

ASSIGNEE(S)	DATE REGISTERED
71	

FULL NAME(S) OF INVENTOR(S)

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NHLAPO, Thabiso James

CHTCHERBAKOV, Anatoli Aleksandrovich

PRIORITY CLAIMED	COUNTRY	NUMBER	DATE
N.B. Use international abbreviation for country. (See Schedule 4)	33	31	32

TITLE OF INVENTION

54 TUNABLE SPECTRAL EQUALISATION FILTER FOR AMPLIFIED SPONTANEOUS EMISSION SOURCES

ADDRESS OF APPLICANT(S) / PATENTEE(S)

Kingsway & University Road
Auckland Park
2006
South Africa

ADDRESS FOR SERVICE	REF
74 D M Kisch Inc, 54 Wierda Road West, Wierda Valley, SANDTON	P26878ZA00

PATENT OF ADDITION NO.	DATE OF ANY CHANGE	
61		
FRESH APPLICATION BASED ON	DATE OF ANY CHANGE	

REPUBLIC OF SOUTH AFRICA
PATENTS ACT, 1978

REVENUE PAID 20.6.03 INKOMSTE BETAAL

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REPUBLIC OF SOUTH AFRICA Form P.1 60.00 REPUBLIEK VAN SUID-AFRIKA

APPLICATION FOR A PATENT AND ACKNOWLEDGEMENT OF RECEIPT

(Section 30 (1) - Regulation 22)
The grant of a patent is hereby requested by the undermentioned applicant on the basis of the present application filed in duplicate.

OFFICIAL APPLICATION NO		DMK REFERENCE
21	01 2003/4813	P26878ZA00

FULL NAME(S) OF APPLICANT(S)

71 RAND AFRIKAANS UNIVERSITY

ADDRESS(ES) OF APPLICANT(S)

Kingsway & University Road
Auckland Park
2006
South Africa

TITLE OF INVENTION

54 TUNABLE SPECTRAL EQUALISATION FILTER FOR AMPLIFIED SPONTANEOUS EMISSION SOURCES

THE APPLICANT CLAIMS PRIORITY AS SET OUT ON THE ACCOMPANING FORM P2 The earliest priority claimed is			
THIS APPLICATION IS FOR A PATENT OF ADDITION TO PATENT APPLICATION NO.	21	01	
THIS APPLICATION IS FRESH APPLICATION IN TERMS OF SECTION 37 AND BASED ON APPLICATION NO.	21	01	

THIS APPLICATION IS ACCOMPANIED BY :

x	1a	A single copy of a provisional specification of 11 pages.
	1b	Two copies of a complete specification of pages.
	2a	Informal drawings of sheets.
x	2b	Formal drawings of 3 sheets.
	3	Publication particulars and abstract (form P8 in duplicate).
	4	A copy of figure of the drawings for the abstract.
	5	Assignment of invention (from the inventors) or other evidence of title.
	6	Certified priority document(s).
	7	Translation of priority document(s).
	8	Assignment of priority rights.
	9	A copy of form P2 and a specification of S.A. Patent Application. 21 01
	10	A declaration and power of attorney on form P3.
	11	Request for ante-dating on form P4.
	12	Request for classification on form P9.
	13a	Request for delay of acceptance on form P4.
	13b	

DATED 20 June 2003

Patent Attorney for Applicant(s)

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REGISTRAR OF PATENTS

REGISTRAR OF PATENTS DESIGNS, TRADE MARKS AND COPYRIGHT 2003 -06- 20 REGISTRATEUR VAN PATENTE, MODELLE, HANDELSMERKE EN OUTEURSREG

The duplicate will be returned to the applicant's address for service as proof of lodging but is not valid unless endorsed with official stamp.

D. M. Kisch Inc, Sandton

Form P.6

REPUBLIC OF SOUTH AFRICA

PATENTS ACT, 1978

PROVISIONAL SPECIFICATION
(Section 30 (1) - Regulation 27)

OFFICIAL APPLICATION NO.			LODGING DATE		DMK REFERENCE
21	01	2003/4813	22	20 June 2003	P26878ZA00

FULL NAME(S) OF APPLICANT(S)	
71	RAND AFRIKAANS UNIVERSITY

FULL NAME(S) OF INVENTOR(S)	
72	SWART, Pieter Lodewikus NHLAPO, Thabiso James CHTCHERBAKOV, Anatoli Aleksandrovich

TITLE OF INVENTION	
54	TUNABLE SPECTRAL EQUALISATION FILTER FOR AMPLIFIED SPONTANEOUS EMISSION SOURCES

TUNABLE SPECTRAL EQUALISATION FILTER FOR AMPLIFIED SPONTANEOUS EMISSION SOURCES

FIELD OF THE INVENTION

This invention relates to a tunable filter for equalising the spectrum of an amplified spontaneous emission source. More particularly, but not exclusively, the invention relates to a tunable filter for spectral equalisation of erbium-doped fiber fluorescent broadband light sources.

BACKGROUND TO THE INVENTION

Broadband light sources in the 1520 nm to 1560 nm spectral range find application in fibre Bragg grating sensors and optical communication systems. The brightness of super-luminescent sources based on the Amplified Spontaneous Emission (ASE) from erbium-doped fibre that is pumped at either 1480 nm or 980 nm, makes them favored candidates for these applications. The output power spectral density of these sources, however, varies considerably and a marked peak is apparent near 1530 nm. The amplitude of this peak is also dependent on the power level of the pump laser.

OBJECT OF THE INVENTION

It is an object of this invention to provide a tunable filter for spectral equalisation of amplified spontaneous emission sources which, at least partially, alleviates the abovementioned difficulty.

SUMMARY OF THE INVENTION

According to the invention there is provided a tunable filter for spectral equalisation of amplified spontaneous emission sources comprising a first optical path and a second optical path; a first tunable optical coupler being connectable to an optical power source, for directing an optical signal from the optical power source to the first and second optical paths in a variable proportion; attenuation/amplification means provided in the first optical path for attenuating or amplifying the optical signal propagating there through; and a second optical coupler for directing a fixed proportion of the optical signals from the first and second paths into two channels, one of which is an output channel.

In a preferred form of the invention the second optical coupler is a 3dB coupler for directing half the optical energy from the first path and half the optical energy from the second path into the output channel. It is envisaged that an equalised power spectrum of the optical power source will be

measurable at the output channel.

The attenuation means may be a Long Period Grating (LPG). Preferably, the attenuation means has its attenuation band at a set of wavelengths corresponding to the peak or peaks in the spectrum of the optical power source, such that the filter acts as a notch filter or a band pass filter.

In one embodiment of the invention the first and second paths are the two arms of a Mach-Zehnder interferometer (MZI).

BRIEF DESCRIPTION OF THE DRAWINGS

A filter for spectral equalization of amplified spontaneous emission sources according to the invention is described below by way of a non-limiting example only and with reference to the accompanying figures, in which:

Figure 1: shows a schematic diagram of a filter according to the invention, including a first tunable coupler;

Figure 2: shows a graph of the theoretical transfer function of the filter of Figure 1 for a range of coupling ratios K_1 of the first tunable coupler;

Figure 3: shows a graph of experimentally determined relative attenuation spectra of the filter of Figure 1 for various values of the coupling ratio K_1 of the tunable coupler; and

Figure 4: shows graphs of amplified spontaneous emission spectra for two settings of the tunable coupler with the pump current at 150 mA and at 180mA respectively.

DETAILED DESCRIPTION OF THE DRAWINGS

A schematic representation of one embodiment of the tunable filter according to the invention is shown in Figure 1.

The filter consists of a first optical path 12 and a second optical path 14; a first coupler in the form of a tunable optical coupler 16; attenuation/amplification means provided in the form of a non-tunable Long Period Grating (LPG) 20 with or without an optical amplifier; and a second coupler in the form of fixed coupler 22 for directing half of the optical signals from the first and second paths 12, 14 into an output channel 24.

The tunable coupler 16 is connectable to an Amplified Spontaneous Emission (ASE) source 18, for directing an optical signal from the ASE source 18 to the

first and second optical paths 12, 14 in a variable proportion. The LPG 20 is provided in the first optical path 12 for attenuating the optical signal propagating there through.

It is envisaged that an equalised power spectrum of the ASE source 18 will be measurable at the output channel 24 with an optical spectrum analyser 26.

Figures 2 and 3 show that the LPG 20 has its attenuation band or bands at a set of wavelengths in the wavelength range (1500nm –1600nm). For this particular embodiment it has only a single peak at 1531nm. This corresponds to the peak in the spectrum of the ASE source, apparent from spectrum shown in Figure 4, such that the filter acts as a notch filter or a band pass filter.

It is further apparent to those skilled in the art that the invention comprises a Mach-Zehnder interferometer having the LPG 20 inserted in one arm, the two arms of the Mach-Zehnder interferometer corresponding with the first and second paths 12, 14. The tunability of the filter arises by incorporating the LPG 20 in a Mach-Zehnder configuration that includes the tunable coupler 16.

The LPG 20 has its attenuation band at the required wavelength corresponding to the peak in the source spectrum. The required maximum attenuation and the bandwidth are achieved by a proper choice of the length, period and refractive index excursion during the design and manufacturing

stage of the LPG 20.

By increasing the coupling ratio of the tunable coupler 16, the ratio of the optical power propagating in the first and second paths 12, 14 changes. If the coupling ratio K_1 of the tuneable coupler 16 is adjustable between 0% and 100%, the optical signal will propagate progressively more through the LPG 20, causing an increasingly larger attenuation of the peak in the power spectral density function measurable at the output channel 24. At the fixed coupler 22, the waves in the first and second arms 12, 14 are summed. If the coherence length of the ASE source 18 is short, interference effects are negligible. It can be assumed that both the tunable and fixed couplers 16, 22 are lossless. Under these assumptions, the power transfer function of the TEF between ports P_1 and P_2 is:

$$T(\lambda)=(1-K_2)\left[1+K_1\left(\frac{K_2}{1-K_2}T_{co}(\lambda)-1\right)\right], \tag{1}$$

where K_1 is the power coupling ratio of the tunable coupler 16. It is assumed that the tunable coupler 16 is tunable between zero and one. K_2 is the power-coupling ratio of the fixed coupler 22. Typically, this would be selected to be 0.5 (3 dB coupler). $T_{co}(\lambda)$ is the transmission spectrum of the LPG 20 for core-to-core propagation and is given by the following expression[1-3]:

$$T_{co}(\lambda)=\cos^2(\gamma L)+\frac{\delta^2}{\gamma^2}\sin^2(\gamma L), \qquad (2)$$

where L is the length and Λ is the period of the LPG 20, κ is the coupling coefficient, $\delta=\left(\pi/\Lambda\right)\left(\frac{\lambda-\lambda_0}{\lambda}\right)$ is the normalized frequency which indicates the deviation from synchronism, and $\gamma=\left(\kappa^2+\delta^2\right)^{1/2}$.

Fig. 2 depicts the calculated relative attenuation function as a function of wavelength for various values of the coupling ratio K_1 of the tunable coupler 16. Because of the use of a 3dB coupler 22 at the output channel 24, the filter has an insertion loss of 3 dB.

A change in attenuation of approximately 14 dB in a wavelength band centered at 1531 nm is achieved. This makes the device ideally suitable for equalization of the output power spectrum of erbium-doped fibre super-luminescent sources. In an experimental demonstration of this application, the power spectral density variation of the source improved from $\pm$4.8 dB to $\pm$1.58 dB in the wavelength range from 1524 nm to 1563 nm

Fig. 3 shows the measured relative transmittance of the filter over the wavelength range 1480 nm to 1580 nm as obtained with a broadband optical source (super-luminescent light-emitting diode) and an optical spectrum

analyzer 26 in an experimental set-up similar to Fig. 1. The ASE source 18 comprised of 16 m erbium-doped fiber and a 980 nm pump laser with maximum output power of 80 mW. Fig. 4 depicts the recorded spectra for pump currents of 150 mA and 180 mA respectively. The coupling ratio K_1 of the tunable coupler 16 is adjusted to either to bypass the LPG 20 completely (dotted lines), or to effect the optimum attenuation value for each of the pump currents respectively. This illustrates the effectiveness of the filter to suppress the peak in the power spectral density of the ASE source 18 around 1530nm.

The experimentally determined characteristics of the tunable attenuation filter correspond very well with the calculated values as can be seen by comparing Figs. 2 and 3. The experimental device was capable of tuning the maximum attenuation at 1530 nm between approximately 0 dB and 14 dB. It is possible to expand this range by employing an LPG with larger coupling from the core mode to the cladding mode of interest. When using the device as spectral equalizer for an ASE source, the ripple in the source spectrum could be reduced from $\pm$6.1 dB to $\pm$1.9dB at a pump laser current of 180 mA. Similar performance was achieved at other pump currents by adjusting the tunable coupler 16 appropriately. For example, for a pump current of 150 mA, the respective values were $\pm$4.8 dB and $\pm$1.58 dB. These values may be improved by using a cascade of normal and phase-shifted LPGs as suggested by Zhu et al.[4] The invention is not limited to the precise details as described above. For example, although a manual system is described, an electronically

controlled tunable coupler 16 incorporated in a closed-loop controller may be used; and the concept may be implemented in integrated optics as opposed to fibre optics.

Tunability of the attenuation filter assures that the spectral ripple can be controlled over a wide range of pump power. It is envisaged that Inserting the LPG 20 in cascade with the ASE source described above 18 will equalize the spectrum. As the pump current is varied to set the output power to the required value, the attenuation of the long-period grating is adjusted because the spectral shape depends on the pump current – thus the necessity for tunability of the attenuation of the LPG 20. For an ASE source 18 with a 15 dB range in output power, it was found experimentally that the peak in the spectrum at 1530 nm varies by more than 10 dB. The adjustable equalizer should therefore have a range of at least 10 dB.

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4. Y. Zhu, B.M. Lacquet, P.L. Swart, S.J. Spammer, P. Shum and C. Lu, "Device for concatenation of phase-shifted long-period grating and its application as gain-flattening fiber filter," Opt. Eng., 42(5), 1445-1450 (2003).

Dated this 20 day of June 2003

Patent Attorney / Agent for the Applicant

RAND AFRIKAANS UNIVERSITY

3 SHEETS
SHEET 1

2003/4813

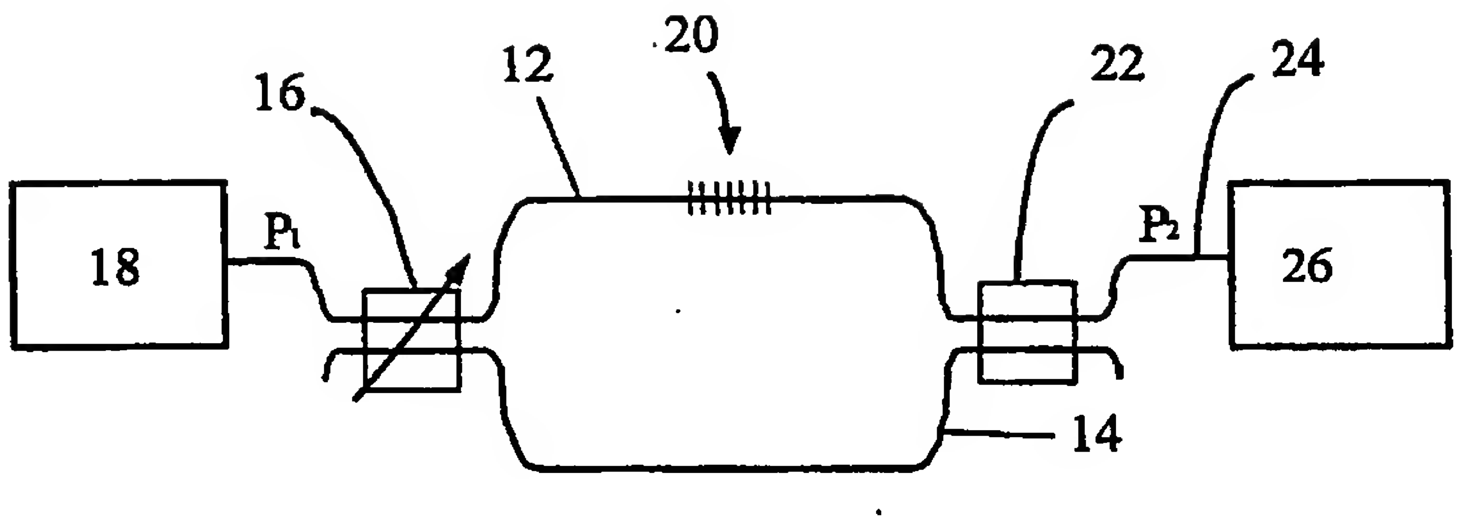

Figure 1

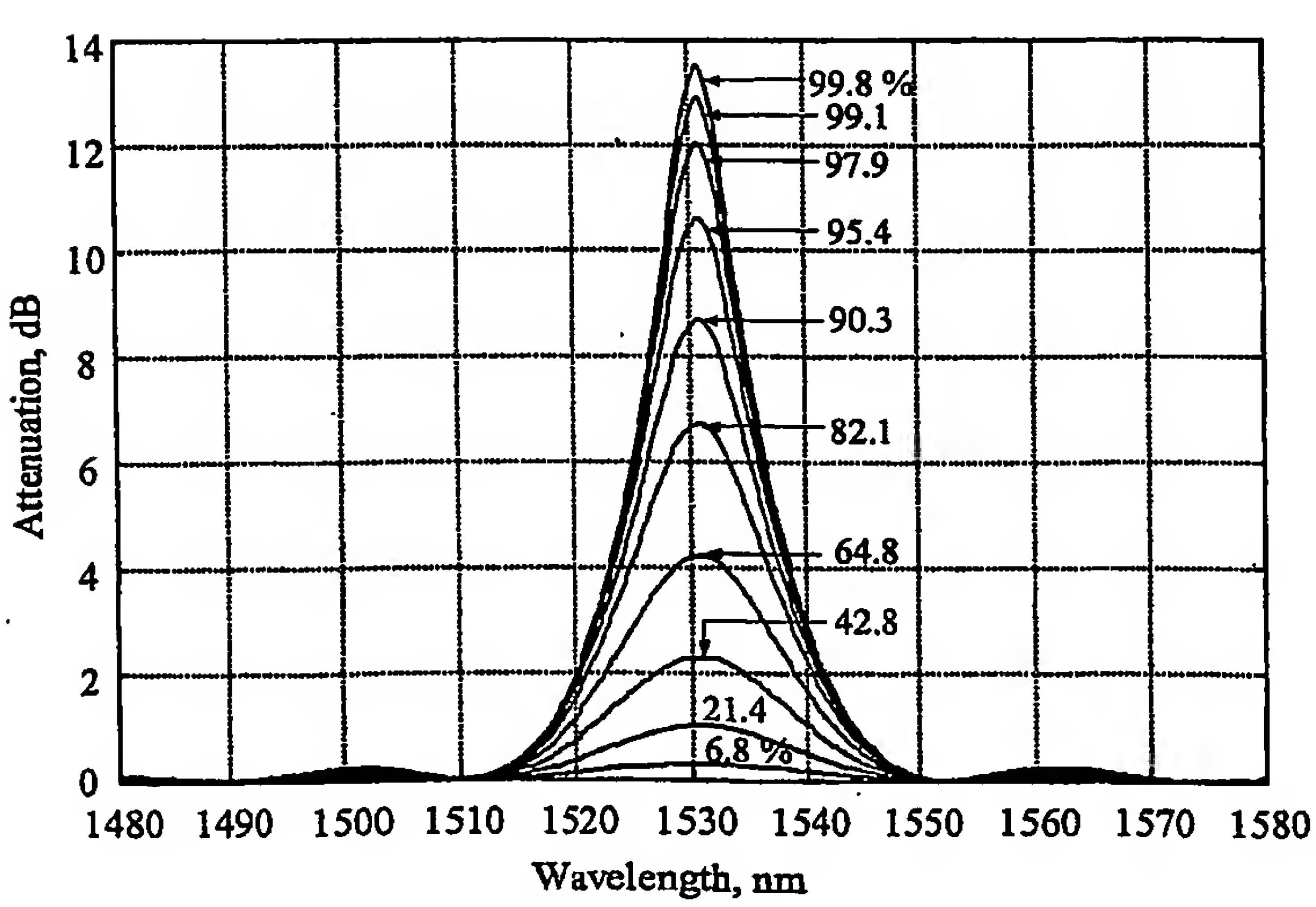

Figure 2

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PATENT ATTORNEYS FOR THE APPLICANT

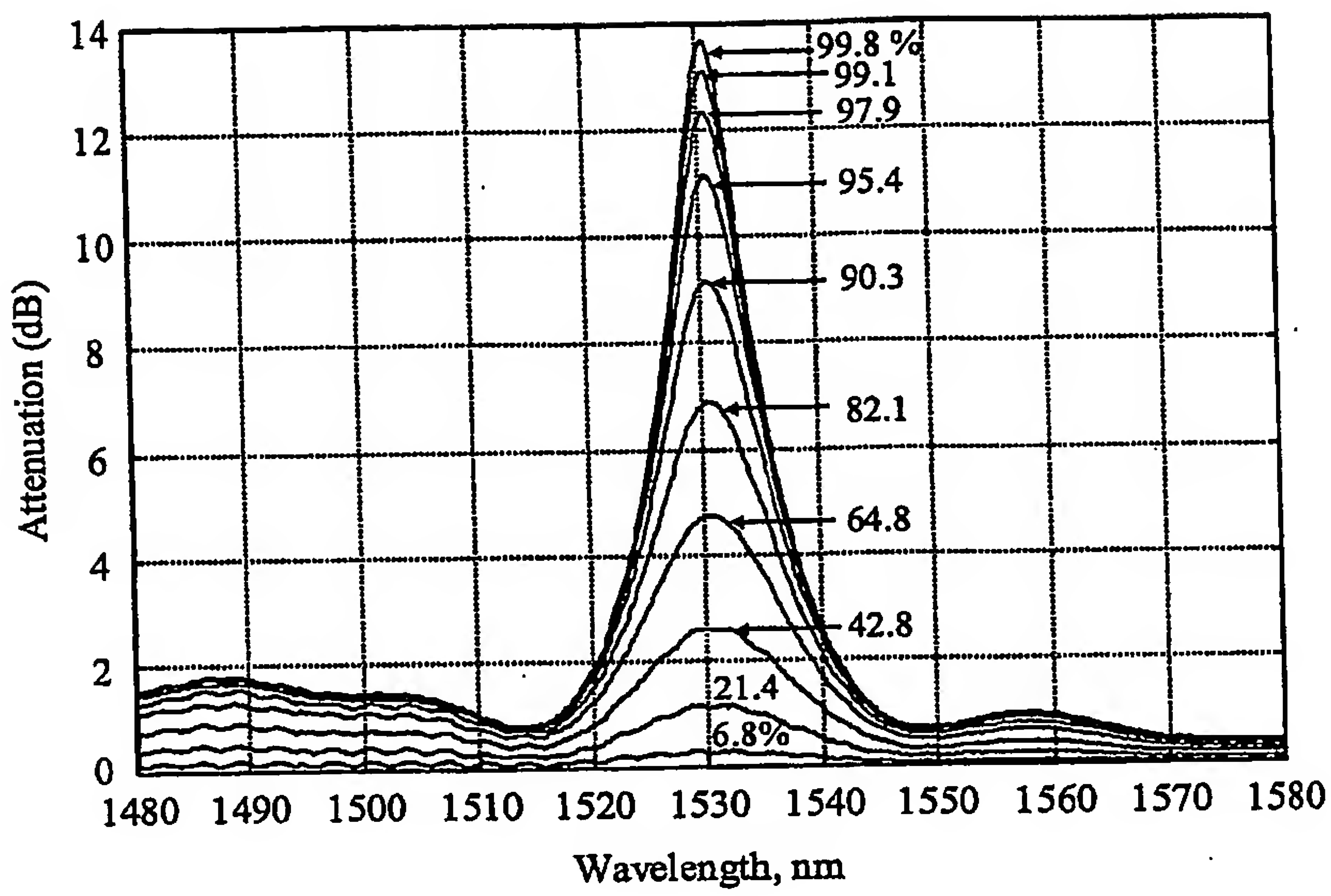
14
12
10
8
6
4
2
0
Attenuation (dB)
99.8 %
99.1
97.9
95.4
90.3
82.1
64.8
42.8
21.4
6.8%
1480
1490
1500
1510
1520
1530
1540
1550
1560
1570
1580
Wavelength, nm

Figure 3

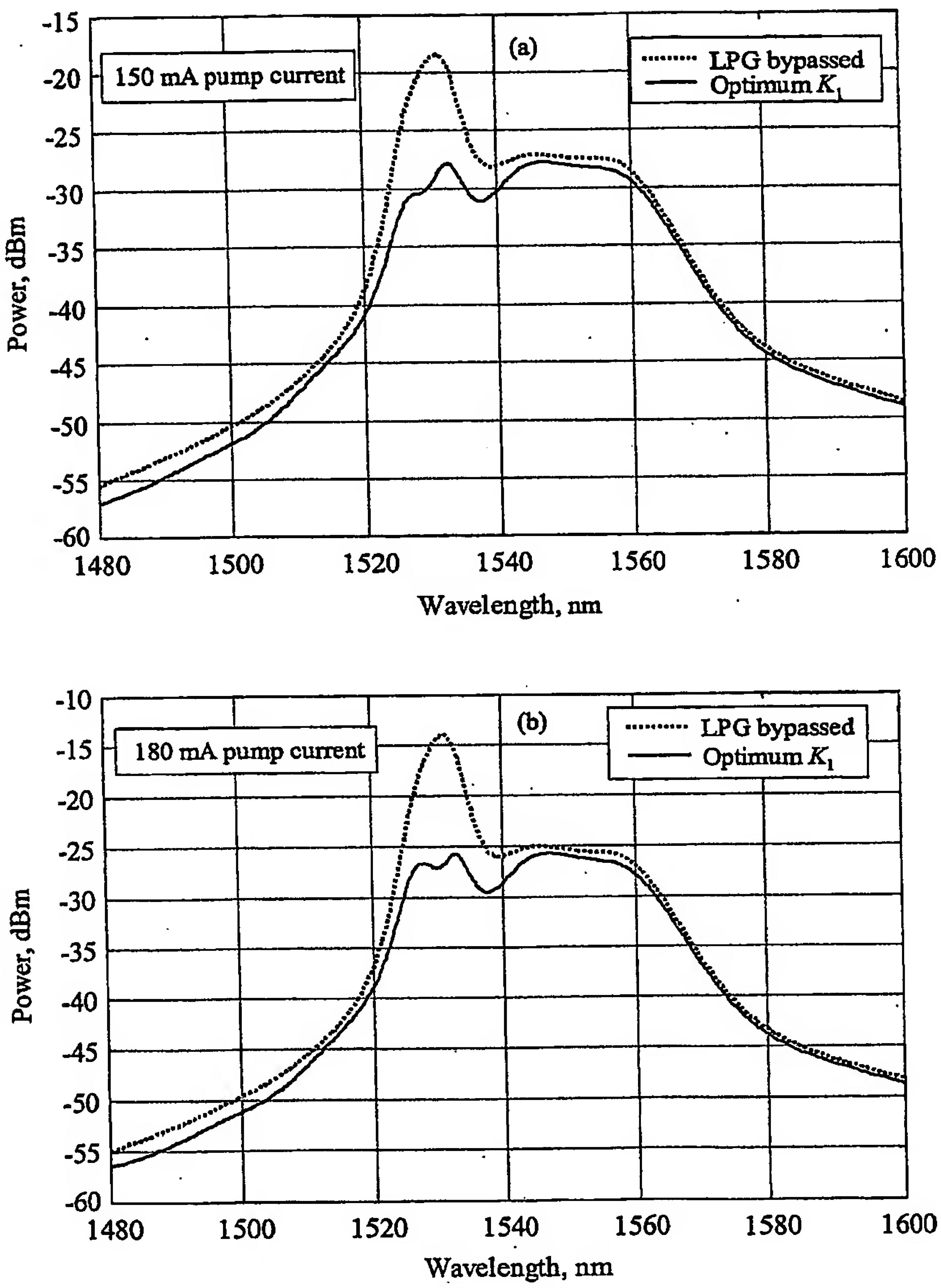
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
Power, dBm
150 mA pump current
(a)
LPG bypassed
Optimum K_1
1480
1500
1520
1540
1560
1580
1600
Wavelength, nm
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
Power, dBm
180 mA pump current
(b)
LPG bypassed
Optimum K_1
1480
1500
1520
1540
1560
1580
1600
Wavelength, nm

Figure 4